(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 205 139 A2

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 86107823.6

(22) Date of filing: 09.06.86

(51) Int. Cl.⁴: H 01 S 3/19
H 01 S 3/06

(30) Priority: 10.06.85 JP 125449/85
13.12.85 JP 280342/85

(43) Date of publication of application: 17.12.86 Bulletin 86/51

(84) Designated Contracting States: DE FR GB NL

(71) Applicant: NEC CORPORATION
33-1, Shiba 5-chome, Minato-ku
Tokyo 108(JP)

(72) Inventor: Mito, Ikuo
c/o NEC Corporation 33-1, Shiba 5-chome
Minato-ku Tokyo(JP)

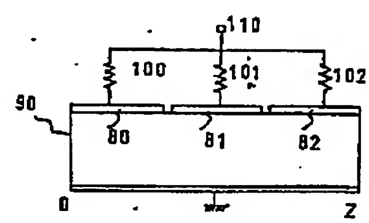
(72) Inventor: Yamaguchi, Masayuki
c/o NEC Corporation 33-1, Shiba 5-chome
Minato-ku Tokyo(JP)

(74) Representative: VOSSIUS & PARTNER
Siebertstrasse 4 P.O. Box 86 07 67
D-8000 München 86(DE)

(54) Distributed feedback semiconductor laser device.

(57) The invention relates to a distributed feedback semiconductor laser device and a method of manufacturing a semiconductor laser. The semiconductor laser device comprises an active layer for emitting light in response to the injection of current, a diffraction grating neighboring said active layer to interact with the light, current injecting means for injecting current into said active layer and control means for controlling the distribution of current which is injected into said active layer in a configuration which corresponds to the field intensity ditribution of the light in the direction of the laser optical axis inside said active layer. The semiconductor laser device is operable in a stable single mode and producible in a high yield.

FIG 3A



EP 0 205 139 A2

DISTRIBUTED FEEDBACK SEMICONDUCTOR LASER DEVICE

Background of the Invention

The present invention relates to a semiconductor laser device usable as, for example, a light source for optical communication, optical measuring apparatuses and others.

A distributed feedback laser diode (DFBLD) or a distributed Bragg reflector laser diode (DBRLD) which is operable in a single mode is a promising light source for high-speed and long-distance optical fiber communication and, due to its good single mode purity of lasing wavelength, for an optical measuring apparatus in which a coherent optical arrangement is built in. Indeed, in an experimental optical fiber communication system whose data rate is as high as 4 Gb/s and transmission distance is longer than 100 km, a DFBLD using an InGaAsP/InP material has been used as a light source and proved to be effectively operable. Further, it has been found that a device with good characteristics shows in a single mode a high output CW operation above 100 mW and a high temperature CW operation as high as 140°C, which are comparable with the characteristics of a conventional Fabry-Perot type semiconductor laser. However, a DFBLD, unlike a Fabry-Perot type laser, cannot readily be provided

with a structure which allows it to lase in single mode. Specifically, Fabry-Perot type laser devices which substantially satisfy necessary conditions can be produced with stability only if the transverse mode is controlled. When it comes to a DFBLD, however, the lasing spectrum varies complicatedly between a single mode and plural modes depending upon various factors such as a particular diffraction grating phase in which the diffraction grating is terminated at an emitting end of the DFBLD, making it difficult to produce devices that are stably operable in a single mode in a high yield.

Summary of the Invention

It is therefore an object of the present invention to provide a semiconductor laser device which is operable in a stable single mode and producible in a high yield.

In accordance with the present invention, there is provided a semiconductor laser device in which a diffraction grating is formed to neighbor an active layer and the distribution of current to be injected into the active layer is controlled to a configuration which substantially corresponds to that of the distribution of field intensity of light along a laser optical axis inside the active layer.

By controlling the current distribution configuration as stated above, the present invention remarkably enhances

the yield of laser chips which are stably operable in a single mode.

Brief Description of the Drawings

FIG. 1A is a section of a prior art DFBLD useful for describing the principle of the present invention;

FIGS. 1B to 1D are plots representative of distributions of field intensity of light and gain in an axial direction of a resonator and also useful for describing the principle of the present invention;

FIG. 2 is a perspective view of a semiconductor laser applicable to a first embodiment of the present invention;

FIG. 3A shows the laser of FIG. 2 to which load resistors are interconnected;

FIG. 3B is a plot showing a distribution of field intensity of light and that of current density in the axial direction of a resonator which are attainable with the arrangement of FIG. 3A:

FIG. 4 is a perspective view of a second embodiment of the present invention;

FIG. 5 is a perspective view of a semiconductor laser applicable to a third embodiment of the present invention;

FIG. 6A shows the laser of FIG. 5 to which load resistors are interconnected;

FIG. 6B is a plot showing a distribution of field intensity of light and that of current density in the axial

direction of a resonator which are attainable with the arrangement of FIG. 6A;

FIG. 7A is a perspective view of a semiconductor laser device representative of a fourth embodiment of the present invention;

FIG. 7B is a section along line A-B-C of FIG. 7A; and

FIGS. 8A to 8D show a basic process for manufacturing the semiconductor laser of FIGS. 7A and 7B.

Principle of the Present Invention

Before entering into detailed description of preferred embodiments of the present invention, the principle of the present invention will be briefly described.

Referring to FIG. 1A, a typical example of DFBLD structures is schematically shown. It has been reported that in a DFBLD providing a $\lambda/4$-shifted region 50 which changes the phase of a diffraction grating by quarter-wave in terms of Bragg wavelength at substantially the center of a laser chip is successful in improving the single-mode lasing characteristic (e.g. "$\lambda/4$-Shifted InGaAsP/InP DFB Lasers by Simultaneous Holographic Exposure of Positive and Negative Photoresists", ELECTRONICS LETTERS, 22nd November 1984 Vol. 20, No. 24). The DFBLD shown in FIG. 1A has such a structure. Low-reflectivity films 30 and 31 are respectively formed on opposite end facets of

the DFBLD to eliminate the influence of reflection otherwise caused by those facets. Among those modes which arise in a resonator of the DFBLD having the structure of FIG. 1A, a one which oscillates at the Bragg frequency and has the lowest lasing threshold shows a field intensity distribution as plotted in FIG. 1B. The distribution shown is a result of calculation performed by assuming that the current injection is effected in a direction perpendicular to the axis of the resonator and uniformly throughout various points in the axial direction of the resonator, and that the gains at the respective points are the same. As shown, the field intensity is greatest at the $\lambda/4$-shifted region 50 which is located at the center of the element and is sequentially attenuated toward the opposite ends. An element provided with the region 50 thereinside is excellent because it oscillates at the Bragg wavelength to allow a substantial difference in lasing threshold gain to be set up between the mode which oscillates at the Bragg wavelength and any other modes.

The curve of FIG. 1B was obtained on the assumption that the gains are uniform along the axis of the resonator. In practice, however, at substantially the center of the resonator the field intensity of light is high and, therefore, a greater amount of injected carriers is consumed resulting in saturation of gain. Taking this

into account, a field intensity distribution and a gain distribution which actually occur are such that, as shown in FIG. 1C, the field intensity is somewhat lower at the center than in the case of FIG. 1B. Where the injection current is increased, the field intensity of light inside the resonator is further increased promoting the tendency that the consumption of injected carriers at and near the center of the resonator is increased and, conversely, the gain at opposite ends of the resonator where carrier consumption is less than at the center is increased. As a result, sub-modes showing a field intensity distribution which, unlike that of the mode which oscillates at the Bragg wavelength, increases at opposite ends of the resonator become more and more liable to oscillate. Finally, the sub-modes begin to oscillate along with the mode which oscillates at the Bragg wavelength or after the latter mode has stopped oscillating. Heretofore, such a phenomenon has not been fully understood because the conventional calculation has in most cases been based on the assumption that the gains in the resonator are uniform.

We manufactured an experimental model having a structure similar to that of FIG. 1A to evaluate its operation and found that sub-modes oscillate more than expected. To account for this fact, it is necessary to consider the configuration of the field intensity

distribution in the axial direction of the resonator. Such a probelmatic situation will be settled if the distribution configuration along the axis of the resonator is controlled such that, as shown in FIG. 1D, there holds a gain distribution which is similar in configuration to the field intensity distribution of a mode that lases at the lowest threshold. Embodiments of the present invention which will be described are characterized in that a current injection distribution has a configuration corresponding to that of a field intensity distribution inside a resonator in the axial direction of the resonator, which is contrastive to a prior art DFBLD.

Detailed Description of the Preferred Embodiments

Referring to FIG. 2, a first embodiment of the present invention is shown in a perspective view. A diffraction grating 60 which is 1000 Å deep and has a pitch of 2000 Å is formed on a (001) n-InP substrate 1 (Sn-doped, carrier density of 1×10^{18} cm^{-3}). The diffraction grating 60 has a $\lambda/4$-shifted region 50 substantially at the center of a resonator. Sequentially formed on the substrate 1 are an n-InGaAsP guide layer 2 (1.15 μm composition in terms of lasing wavelength, Sn-doped, carrier density of 7×10^{17} cm^{-3}), a nondoped InGaAsP active layer 3 (1.30 μm composition in terms of lasing wavelength, 0.1 μm thick), and a p-InP cladding layer 4 (Zn-doped, carrier density of 1×10^{18} cm^{-3},

0.7 μm thick). Thereafter, two parallel grooves 71 and 72 each being 3 μm deep and about 8 μm wide are formed in the (110) direction with a mesa stripe 70 intervening therebetween, the mesa stripe 70 being about 1.5 μm wide at the top thereof. Further, a p-InP blocking layer 5 (Zn-doped, carrier density of 1×10^{18} cm^{-3}, 0.5 μm thick in flat portions), and an n-InP confining layer 6 (Te-doped, carrier density of 5×10^{18} cm^{-3}, 0.5 μm thick in flat portions) are grown one upon the other except for the region above the mesa stripe 70. This is followed by covering the whole area of the laminate with a p-InP embedding layer 7 (Zn-doped, carrier density of 1×10^{18} cm^{-3}, 1.5 μm thick in flat portions) and a p-InGaAsp cap layer 8 (Zn-doped, carrier density of 1×10^{19} cm^{-3}, and 1.0 μm thick in flat portions). This completes a double channel planar buried heterostructure wafer. An SiO_2 insulating film 74 is formed above the mesa stripe 70 except for an injecting region 73 which is 10 μm wide. A first, a second and a third p-side metal electrodes 80, 81 and 82 are separated from each other at the intervals of 100 μm by 5 μm wide separating grooves 84 and 85 each of which extends down to the p-InGaAsP layer 8 perpendicularly to the mesa stripe 70. An n-side metal electrode 83 implemented with AuGeNi is provided on the substrate 1 side. Cleaved facets at opposite ends of

the wafer are respectively provided with films (SiN films in this particular example) 30 and 31 the reflectivity of which is lower than 2%.

When the first to the third metal electrodes 80, 81 and 82 were short-circuited to measure the injection current versus light output characteristic, the lasing threshold at a temperature of 25°C was found to be 30 mA and the differential quantum efficiency with respect to light output from the front end 90, 20%. Concerning lasing spectra, although some laser chips successfully operated with stability up to a high output range above about 30 mW in terms of one-side output, many other chips showed mode hopping and lased in multiple modes at about 5 mW.

In light of the above, as shown in FIG. 3A, load resistors 100, 101 and 102 having values 100 Ω, 50 Ω and 100 Ω, respectively, were respectively connected to the first to the third p-side electrodes 80 to 82 for an experimental purpose. In this arrangement, as a current is fed through a terminal 100 to the laser chip, a current substantially twice greater than those through the first and the third electrodes 80 and 82 flows through the second or intermediate electrode 81. This allows an injection current density distribution to be developed toward the axis of the resonator, as represented by a broken curve

in FIG. 3B. At the borders between the nearby p-side electrodes, the distribution appears smoothly curved and not stepwise because the electric resistance between the first to the third electrodes 80, 81 and 82 is as small as about 20 Ω which allows current to flow from below the second electrode 81 toward the opposite sides. The current density distribution of FIG. 3B resembles in configuration a field intensity distribution which is represented by a solid curve in FIG. 3B. Hence, the arrangement of FIG. 3A is expected to cause the laser to lase in a single mode more stably than the previously mentioned arrangement wherein the electrodes 80 to 82 are short-circuited.

Various characteristics of the laser chip were evaluated by supplying current through the terminal 110. It was proved that the laser operates in a stable single mode with a lasing threshold of 20 mA at 25°C and up to substantially the limit of light output from the front end 90, i.e. about 50 mW. The differential quantum efficiency with respect to the light output from the facet 90 was 25%. Thus, it was proved that a chip with a current density distribution approximated in configuration to an internal field intensity distribution is operable substantially in a stable single mode, and that substantially 80% of such chips show a stable single mode operation up to 30 mW and above, demonstrating the effectiveness of the structure in accordance with the present invention.

Referring to FIG. 4, a second embodiment of the present invention is shown. While in the diagram of FIG. 3 the load resistors 100, 101 and 102 are provided in leads which are adapted to feed current into the laser, they may alternatively be arranged on a high resistance Si heat sink 200 as shown in FIG. 4. The semiconductor laser chip of FIG. 2 is interconnected by fusing to patterned wirings 201, 202 and 203 the first to the third p-side electrodes 80, 81 and 82 up, the wirings 201, 202 and 203 each being 5 μm thick and made of AuSn. The chip resistors 100, 102 and 102 are respectively interconnected by fusing to the wirings 201, 202 and 203 and a terminal 204 which is also 5 μm thick and made of AuSn, thereby electrically interconnecting the wirings and the terminal. The chip resistors 100, 101 and 102 are 100 Ω, 50 Ω and 100 Ω in resistance, respectively. Bonding wires 300 and 301 are respectively connected to the n-side electrode 83 of the laser and the terminal 204. Such a structure made it possible to form the external load resistors of FIG. 3 in a hybrid configuration on the heat sink 200 of the laser.

Referring to FIG. 5, a third embodiment of the present invention is shown. This embodiment differs from that of FIG. 2 in that a high reflectivity film 32 is deposited by vapor deposition on the rear facet 91 to enhance the reflectivity of the facet 91 to 90%. The film 32 has a

four-layer configuration, i.e. SiO_2/amorphous Si/SiO_2/ amorphous Si. In the structure shown in FIG. 5, the $\lambda/4$-shifted region is needless and, therefore, not formed. As represented by a solid curve in FIG. 6B, the laser with the structure of FIG. 5 shows a field intensity distribution which increases toward the high reflectivity facet 32. In this case, the p-side electrode is divided into the first and the second electrodes 80 and 81. FIG. 6A shows the load resistors 100 and 101 having resistance values 100 Ω and 50 Ω, respectively, which are respectively interconnected to the first and the second p-side electrodes 80 and 81, as in the first embodiment. FIG. 6B shows a current density distribution and a field intensity distribution which are attainable with the arrangement of FIG. 6A. It will be seen that the two distributions resemble each other in configuration.

An experiment was conducted with the arrangement of FIG. 6A so as to evaluate the characteristics of the laser; the lasing threshold was measured to be 20 mA, the maximum output of light from the front facet 120 mW, and the differential quantum efficiency as great as 60% at maximum at room temperature. A laser having such a structure may be considered as substantially resembling a laser having a $\lambda/4$-shifted region thereinside except that the region 50 is relocated to the position of the high reflectivity

film 32. The laser of FIG. 5 was found to operate stably in a single mode and most of such lasers were proved to be operable in a stable single mode up to a light output range above 50 mW. Also, it was revealed that the laser of FIG. 5 is easy to achieve a high output and a high efficiency characteristic, compared to that of FIG. 2.

Although each of the foregoing embodiments has been shown and described as having two or three fragments of p-side electrode, such particular numbers are only illustrative. That is, the greater the number of electrode fragments, the more the current distribution configuration matches with the field intensity of light inside the laser.

While in the embodiments shown and described so far the electrode is divided in order to control the current distribution configuration, this kind of approach involves the need for troublesome procedures such as interconnecting resistors having different values to the individual electrode pieces. It is therefore desirable to form in a semiconductor chip a structure for controlling the current distribution configuration. This demand may be met by suitably distributing different resistance values along a current path which extends from an electrode to an active layer inside a semiconductor chip. Generally, the resistance value of a semiconductor layer is variable by changing the carrier density; for example, the specific

resistance ρ of a p-InP layer is about 0.1 Ω-cm when the carrier density is 1×10^{18} cm^{-3} and doubled to about 0.2 Ω-cm when it is reduced to 4×10^{17} cm^{-3}. It follows that where a carrier density distribution is set up in a semiconductor layer along a current path which terminates at an active layer, the value of current which flows through the active layer can be changed even though the electrode on the surface of a semiconductor layer may be the same. Hence, the current which flows toward the active layer may be distributed in correspondence with the field intensity distribution along the axis of a resonator inside the semiconductor laser.

Referring to FIGS. 7A and 7B, a fourth embodiment of the present invention is shown which is derived from the above-described alternative principle. The DFBLD in accordance with this particular embodiment includes a $\lambda/4$-shifted region 50, where the period of corrugations is inverted, which is positioned at the center of an n-InP substrate 1. Fundamental steps of a process for manufacturing the DFBLD with such a structure will be described with reference to FIGS. 8A to 8D. First, a diffraction grating 60 is formed on the (001) n-InP substrate 1 (carrier density of 1×10^{18} cm^{-3}) (FIG. 8A). The diffraction grating is provided at the center thereof with a $\lambda/4$-shifted region 50 where the period of

corrugations is inverted. The diffraction grating 60 was formed by interference exposure using an He-Cd gas laser whose wavelength was 321 nm. The period of the diffraction grating 60 was 2000 Å and the depth thereof, 800 Å. Then, as shown in FIG. 8B, an n-InGaAsP guide layer 2 (1.15 μm composition in terms of lasing wavelength, 0.1 μm thick in the troughs of the grating 60, Sn-doped, carrier density of 7 x 10^{17} cm^{-3}), a nondoped InGaAsP active layer 3 (1.3 μm composition in terms of lasing wavelength, 0.1 μm thick), a p-InP cladding layer 4 (0.5 μm thick, Zn-doped, carrier density of 1 x 10^{18} cm^{-3}) and a p^--InP second cladding layer 9 (0.5 μm thick, Zn-doped, carrier density of 4 x 10^{17} cm^{-3}) are sequentially formed on the n-Inp substrate 1 by liquid phase epitaxy. In this condition, as shown in FIG. 8C, an SiO_2 film 500 is formed on the whole surface and, then, partly removed in a 100 μm wide stripe configuration in a direction perpendicular to sheet surface of FIG. 8C by photolighography. In this condition, Zn is selectively diffused to the depth of about 0.7 μm penetrating the p^--InP second cladding layer 9, thereby forming a low resistance region 400. The carrier density of the low resistance region 400 was found to have increased to 3 x 10^{18} cm^{-3} while the specific resistance of the region 400 was found to have decreased to about 0.04 Ω-cm. Then, the SiO_2 film 500 is removed by chemical etching,

as shown in FIG. 8D. This is followed by forming a double channel planar buried heterostructure as shown in FIG. 7A using the substrate, as has been the case with the embodiment of FIG. 2. A p-side electrode 86 using Cr/Au metal of a current confining structure which is implemented by an SiO_2 insulating film is formed on the surface of the p-InGaAsP cap layer 8. An n-side electrode 83 using an AuGeNi metal is formed on the substrate 1 side of the wafer by polishing that side until the total thickness of the wafer decreases to 140 μm. Subsequently, the laminate is cleaved to a resonator length of 300 μm such that the low resistance region 100 is located substantially at the center, whereafter SiN is deposited by vapor deposition on opposite facets to provide low reflectivity films 30 and 31 each having reflectivity of about 2%.

FIG. 7B is a section along line A-B-C of FIG. 7A, specifically along substantially the center of the mesa stripe 70, and representative of an emitting portion of the active layer 3. When the p-side electrode 86 was biased to the positive polarity and the n-side to the negative polarity and current was injected into the active layer 3, the laser oscillated at a threshold of 20 mA. Light outputs from the front and rear facets were found substantially equal to each other, and the differential quantum efficiency of the sum of light emitted from the

opposite facets was 60%. As regards the lasing spectrum, the wavelength in a single mode was measured to be 1.305 μm. The injection current versus light output characteristic was free from kink otherwise brought about by mode hopping and other causes; stable single mode operation was maintained up to a high output range above 40 mW.

Moreover, more than 70% of such laser chips showed stable single mode operation.

Presumably, the desirable chip characteristics as well as high yield are accounted for by the following reason. In FIG. 7B, where current is fed with the p-side electrode 86 and the n-side electrode 83 biased to the positive and the negative, respectively, the specific resistance of the p^--InP second cladding layer is about 0.04 Ω-cm in the low resistance region 400 but about 0.2 Ωcm in the other region, implying an about five times of difference. In this condition, the current flowing into the active layer 3 is distributed in a configuration similar to a one which is represented by the broken line in FIG. 3B, the current density distribution therefore being similar to field intensity distribution. Hence, even if the injected current is increased, the mode which shows the field intensity distribution as represented by the solid line of FIG. 3B lases stably with the other modes which show different

distributions hardly allowed to lase. This presumably is the reason why laser chips which operate in a stable single mode can be manufactured with good reproducibility and uniformity.

In the embodiment of FIG. 7A, the low resistance region 400 is located at the center of the element. If desired, the $\lambda/4$-shifted region 50 may be omitted and the reflectivity of the SiN reflective film 31 on the right-hand side may be increased to 90%, in which case the region 400 needs to be located in the vicinity of the end face at the right-hand side because the field intensity along the resonator inside the laser would increase toward the right end facet. Selective diffusion of Zn used in the foregoing embodiments to form the particular region 400 may be replaced with any other suitable implementation such as ion injection of Be or the like. While the cladding layer has been shown and described as being made up of a low resistance layer and a high resistance layer, such is only illustrative. For example, the cladding layer may be comprised of a low resistance layer only and an impurity compensating region may be formed in a region adjacent to the light emitting facet, for the purpose of enhancing the resistance and setting up a resistance region which is distributed along the resonator. Further, the buried stripe structure shown and described is not limitative

and may be substituted for by any other suitable stripe structure without impairing the effects. Stated another way, the stripe structure does not constitute any essential part of the present invention.

CLAIMS

1. A semiconductor laser device comprising:

an active layer for emitting light in response to injection of current;

a diffraction grating neighboring said active layer to interact with the light;

current injecting means for injecting current into said active layer; and

control means for controlling a distribution of current, which is injected into said active layer, in a configuration which corresponds to a field intensity distribution of light in a direction of laser optical axis inside said active layer.

2. A semiconductor laser device as claimed in claim 1, wherein said current injecting means comprises a positive and a negative electrode, one of said positive and negative electrodes which is closer to said active layer than the other comprising divided electrodes.

3. A semiconductor laser device as claimed in claim 2, wherein load resistors are connected one to each of said divided electrodes.

4. A semiconductor laser device as claimed in claim 3, wherein said divided electrodes are interconnected by fusing one to each metal which is provided on a heat sink for divisional fusing.

5. A semiconductor laser device as claimed in any of claims 1 to 4, wherein said semiconductor laser device comprises a semiconductor laser device including a cladding layer which neighbors said active layer and is greater in bandgap than said active layer, said cladding layer having a resistivity which varies in the laser optical axis direction and in correspondence with the field intensity distribution of light.

6. A semiconductor laser device as claimed in any of claims 1 to 5, wherein said diffraction grating includes a phase shifted region where a phase of said diffraction grating is shifted by quater-wave.

7. A semiconductor laser device as claimed in claim 6, wherein each of opposite ends of said active layer is provided with a reflective film forming low reflectivity.

8. A semiconductor laser device as claimed in any of claims 1 to 7, wherein one of opposite ends of said active layer is

provided with a reflective film forming high reflectivity and the other end a reflective film forming low reflectivity.

9. A method of manufacturing a semiconductor laser, comprising the steps of:

forming on a semiconductor substrate of a first conductivity type an active layer and a guide layer which is positioned in the vicinity of and above or below said active layer and has a periodically corrugated surface, and forming a cladding layer made up of a low resistance and a high resistance layer on a laminated structure which consists of said active layer and guide layer; and

forming in a part of said high resistance layer of said cladding layer by ion injection a low resistance layer which is distributed along an axis of a resonator and extends throughout said high resistance layer to said low resistance layer.

FIG. 1A

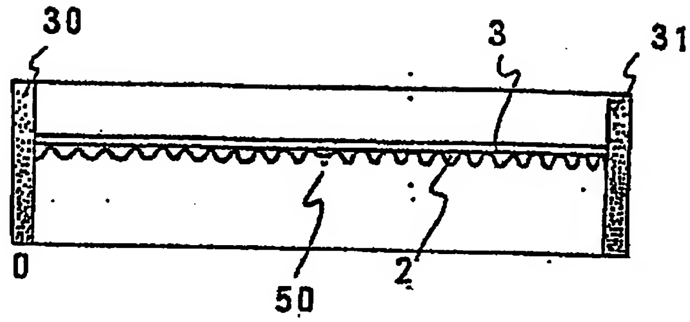


FIG. 1B

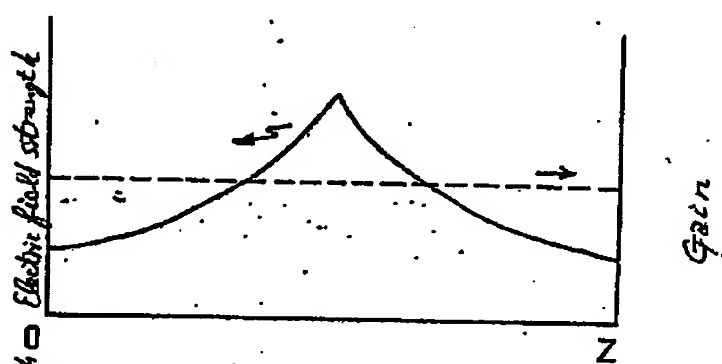


FIG. 1C

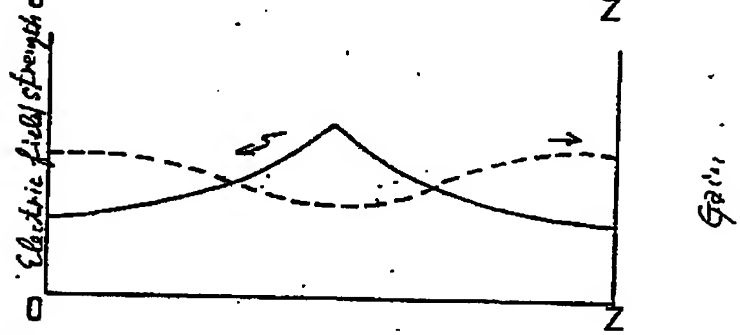


FIG. 1D

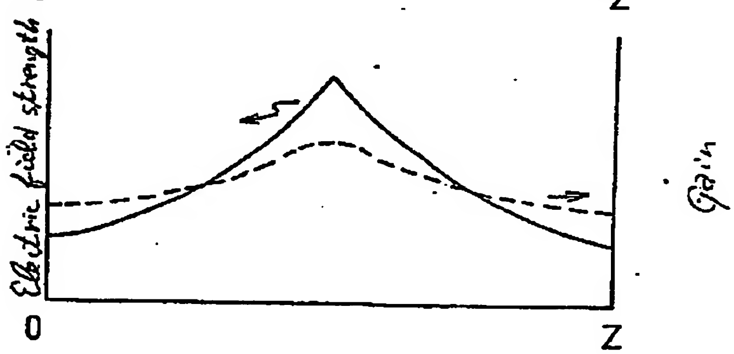
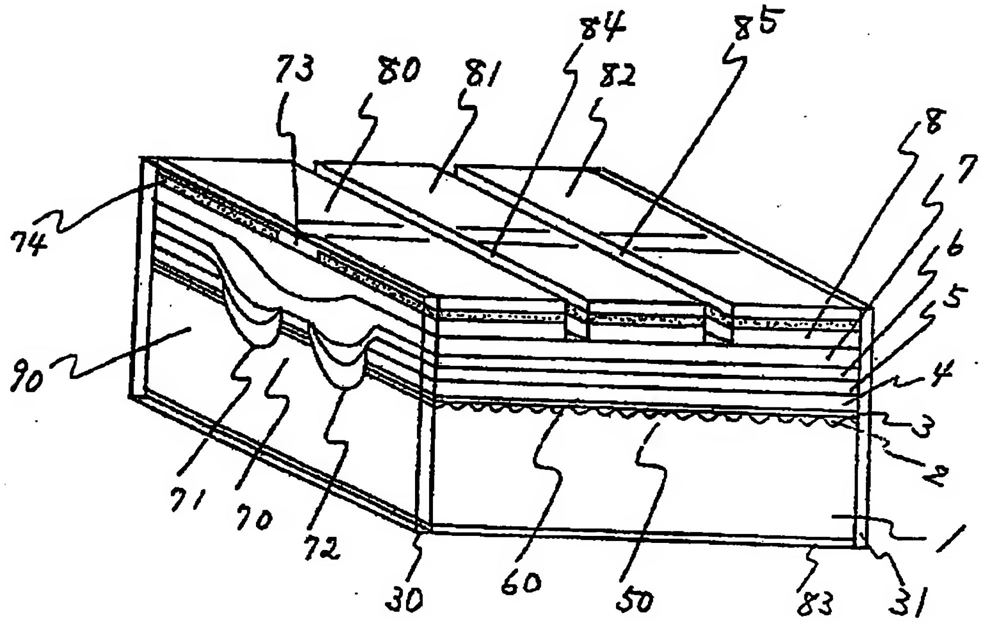


FIG. 2



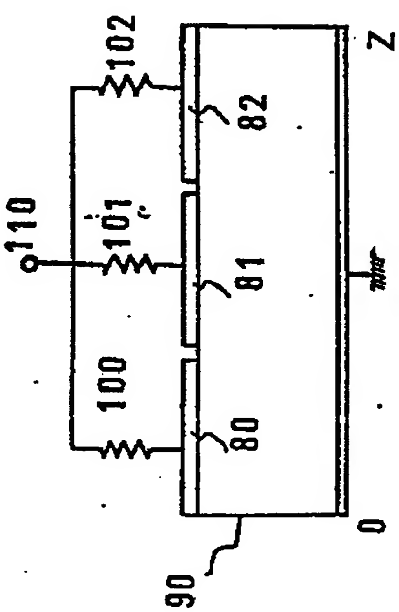

110
100
101
102
80
81
82
90
0
Z

FIG.3A

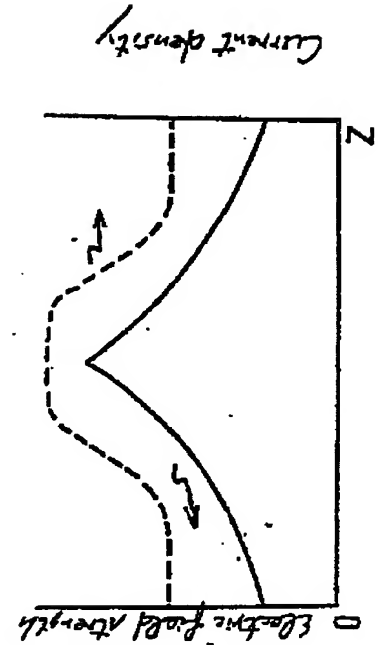

Current density
Electric field strength
0
Z

FIG.3B

FIG. 4

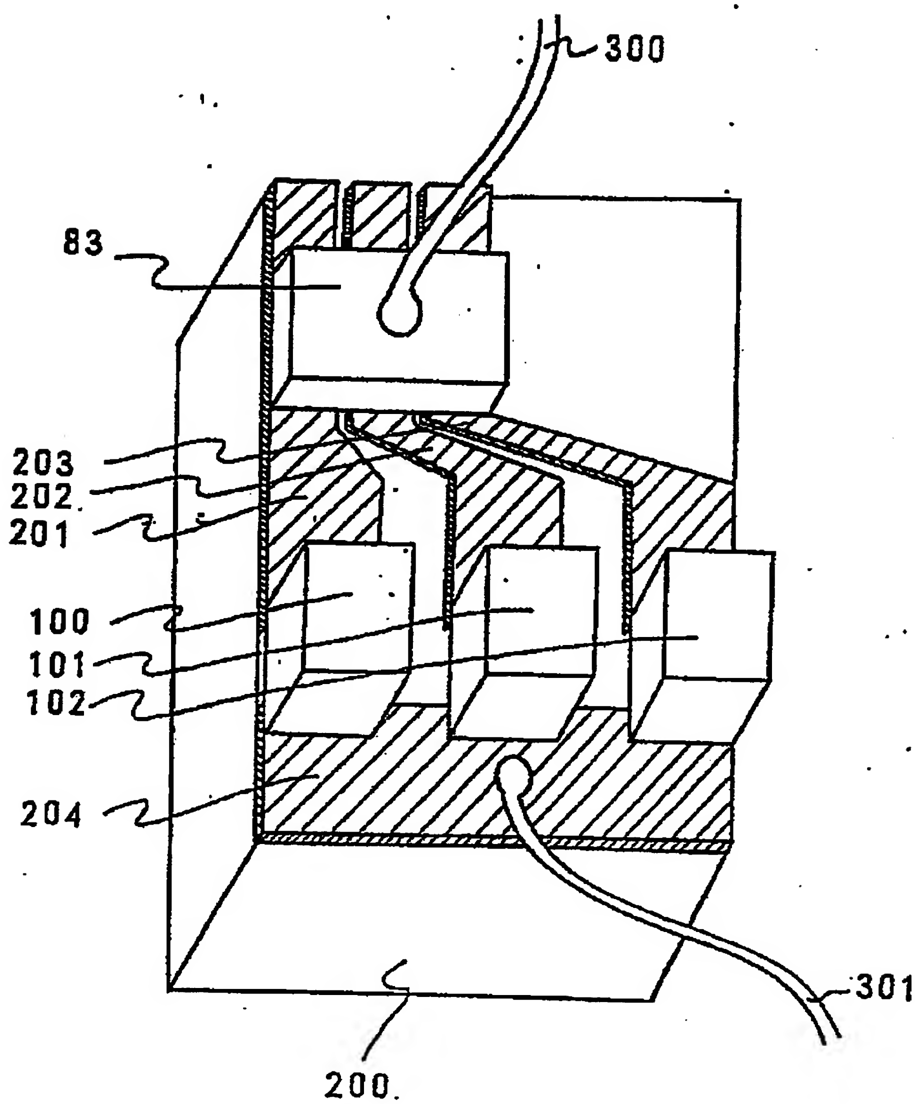
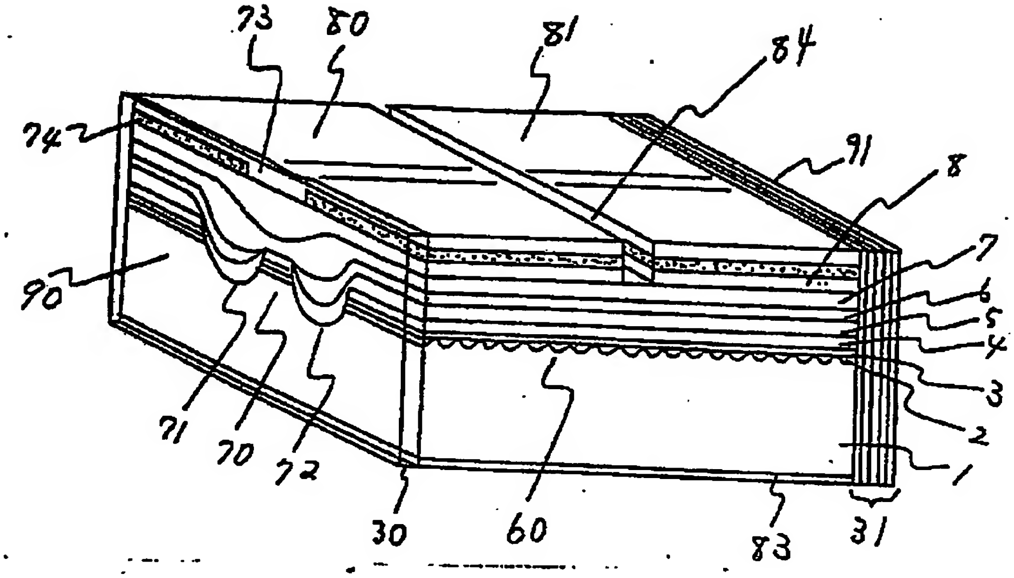


FIG.5



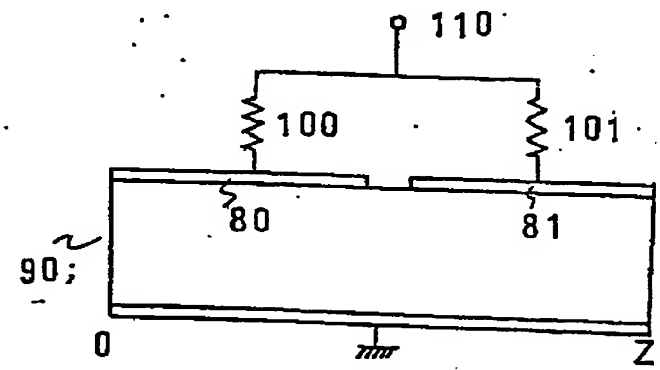


FIG.6A

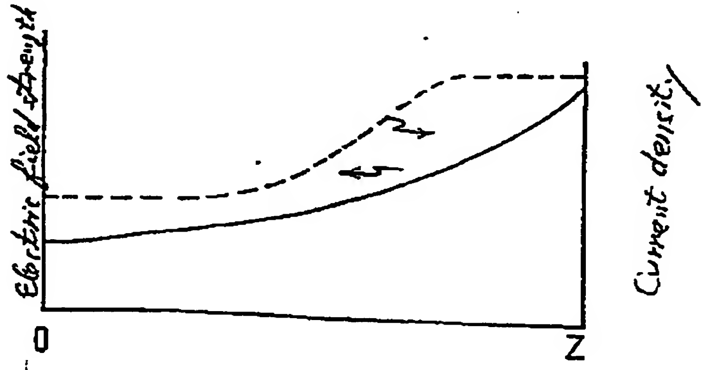


FIG.6B

FIG.7A

(a)

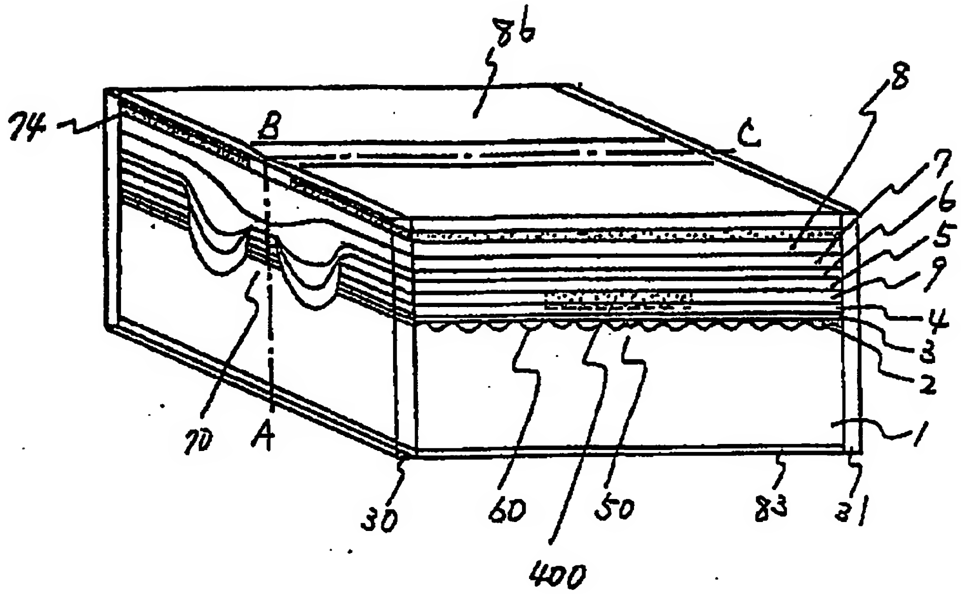


FIG.7B

(b)

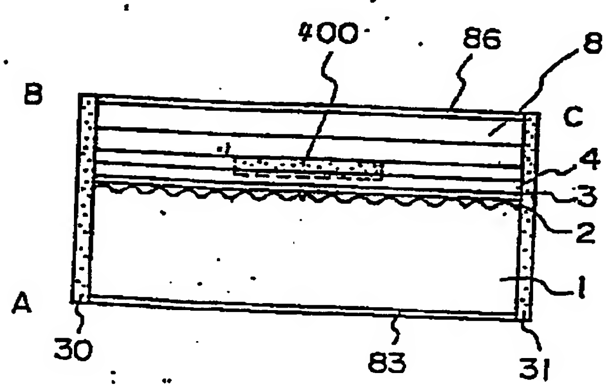


FIG. 8A

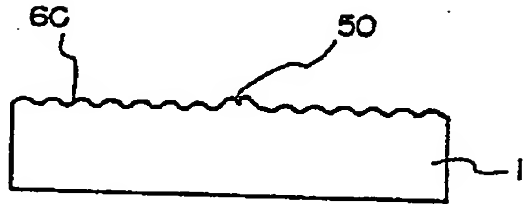


FIG. 8B

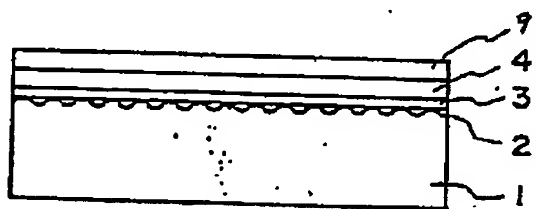


FIG. 8C

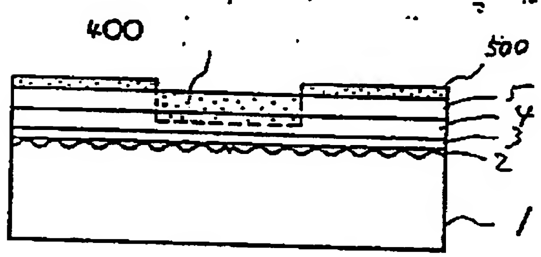


FIG. 8D